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SHORT COMMUNICATION

Soil nitrogen dynamics in canola agroecosystems of eastern Canada

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Abstract: Canola (*Brassica napus* L.) is a nitrogen (N)-demanding crop, so tissue N analysis should be related to soil N supply. We evaluated canola N uptake in relation to soil N pools in plots receiving 0, 50, 100, and 150 kg N·ha^{-1} from urea at three sites in eastern Canada in 2012. Soil N pools varied significantly at the rosette, flowering, pod filling, and maturity stages, but responded less predictably to urea. Canola N uptake was inconsistently related to soil N pools and urea input. This confirms the importance of site-specific N fertilizer management when growing canola in eastern Canada.

Key words: Brassica crops, mineral N, nitrogen fertilizer guidelines, rapeseed, site-specific fertilization.

Résumé : Le canola (*Brassica napus* L.) est une culture qui nécessite beaucoup d'azote (N). Par conséquent, la concentration de N dans les tissus devrait être corrélée à la quantité de N présente dans le sol. En 2012, les auteurs ont évalué l'absorption du N par le canola en fonction de la réserve de N dans les parcelles bonifiées avec 0, 50, 100 ou 150 kg de N sous forme d'urée, à trois endroits, dans l'est du Canada. La quantité de N dans le sol varie sensiblement aux stades de la rosette, de la floraison, du remplissage des gousses et de la maturité, mais elle réagit de façon moins prévisible aux applications d'urée. L'absorption du N par le canola présente des liens incohérents avec la réserve de N dans le sol et les apports d'urée, ce qui confirme l'importance d'une gestion des engrais N adaptée au site pour la culture du canola dans l'est du Canada. [Traduit par la Rédaction]

Mots-clés : culture des brassicacées, N minéral, recommandations sur les engrais azotés, colza, fertilisation adaptée au site.

Introduction

Canola acreage is expanding in eastern Canada due to increased processing capacity of crushing facilities in Quebec and Ontario, which produce edible oil, high-protein meal to supplement animal feed, and biofuel (Ma et al. 2015). Canola is considered a specialty crop in eastern Canada, with 25.7–36.5 thousand Mg oilseed·y^{-1} produced in Quebec from 2016 to 2019 (Institut de la statistique du Québec 2019), whereas Alberta produced 5320–6826 thousand Mg oilseed·y^{-1} during the same period (Statistics Canada 2021). Agronomic practices to optimize canola growth, such as nitrogen (N) fertilization guidelines, were developed in western Canada, but these may not be suitable in eastern Canada. Nitrogen leaching and gaseous loss are more likely in the humid temperate soils of eastern Canada than in semi-arid western Canada, but N mineralization rates from soil organic matter and residues are also higher (St. Luce et al. 2011). It is possible that canola will benefit from higher fertilizer N rates in eastern Canada.

Region-specific fertilizer N guidelines for canola must consider soil N dynamics in relation to crop N uptake.

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Our objectives were to (*i*) determine soil nitrate (NO_3-N), ammonium (NH_4-N), and microbial biomass N (MBN) concentrations in canola field plots with variable N fertilizer inputs and (*ii*) relate these soil N pools to canola N uptake at key growth stages, based on data from three canola field sites in eastern Canada.

Materials and Methods

Site descriptions

Field experiments were established in the 2012 growing season. The Emile A. Lods Agronomy Research Centre in Ste-Anne-de-Bellevue, Quebec (45°03′ N, 74°11′ W, later referred to as "Ste-Anne") was on a sandy loam soil of the Chicot series (Humic Gleysol) with pH 5.0 and 34.0 g organic matter·kg^{-1}, and fallow in the preceding crop year. The Université Laval Experimental Farm near Saint-Augustin-de-Desmaures, Quebec (46°44′ N, 71°31′ W, later referred to as "Quebec"), was on a sandy loam soil of the Orthic series (Dystric Brunisol) with pH 6.1 and 37.0 g organic matter·kg^{-1}, and wheat (*Triticum aestivum* L.) grown in the preceding crop year. The Central Experimental Farm of Agriculture and Agri-Food Canada, Ottawa (45°38′ N, 74°58′ W, later referred to "Ottawa") was on a sandy loam soil of the Orthic series (Melanic Brunisol) with pH 6.5 and 40.3 g organic matter·kg^{-1}, and soybean (*Glycine max* (L.) Merr.) grown in the preceding crop year.

Experimental design

Plots in this study were a subset of treatments from a larger field experiment described by Ma et al. (2015, 2019). Briefly, the field experiment had 26 treatment combinations, arranged in a randomized complete block design with four replicate blocks. We investigated the N treatment factor (fertilizer N application rate) with four levels (0, 50, 100, 150 kg N·ha^{-1}) and four blocks at each site, giving 16 plots per site and 48 plots in total at the three sites. Plot dimensions were 2.6 m × 4 m with a 0.50 m spacing between each plot and 1.3 m wide buffer zone between blocks.

Urea [$(NH_2)_2CO$, 46-0-0] was broadcast on the soil surface, then incorporated to a depth of 0.10 m about 24–48 h before seeding canola (*Brassica napus* L. cv. InVigor 5440, LL) at a rate of 5 kg·ha^{-1} and seeding depth of 1–2 cm. If necessary, the plots received a basal application of phosphorus and potassium fertilizers according to the soil test recommendation for the site, but no sulfur or boron was applied, and the fields were not irrigated. Cultural practices (basal fertilization, tillage, weed control) and the daily mean temperature and precipitation at each site are described in Ma et al. (2015).

Plant sampling and analysis

In 2012, canola plants were collected from each plot at four growth stages: (*i*) rosette (May), (*ii*) 20% flowering (June), (*iii*) 80% pod filling (July), and (*iv*) 90% physiological maturity (August). Five representative plants were randomly uprooted from the first seven rows of each plot. Roots and shoots were separated, washed, dried at 60 °C, and weighed to determine biomass. Dried plant components were finely ground (<0.1 mm) and N concentration was analyzed by combustion at 900 °C with a Thermo Finnigan Flash EA 1112 series C/N analyzer (Carlo Erba, Milan, Italy). Unfortunately, samples were lost from flowering and pod filling stages at Ste-Anne. Canola N uptake was the sum of the biomass × N concentration for roots and shoots in each plot, and the complete dataset is provided in Gurung (2014).

Soil sampling and analysis

Composite soil samples (0–20 cm, sieved <4 mm in the field) were collected from each plot at the canola growth stages described above. Soil was stored at 4 °C until analysis, within 7 d. The soil mineral N (NH_4-N + NO_3-N) concentration was determined in a 10 g subsample of field-moist soil extracted with 0.5 M K_2SO_4 (1:4 soil:extractant) followed by colorimetric analysis of NH_4-N and NO_3-N concentrations at 650 nm using a modified indophenol blue method. Soil MBN concentration was analyzed by chloroform fumigation-direct extraction after comparing the dissolved N concentration in persulfate digests of fumigated and unfumigated field-moist soils extracted with 0.5 M K_2SO_4 (1:4 soil:extractant). Soil MBN concentration was calculated as [(total N in fumigated soil extracts — total N in unfumigated soil extracts)/0.54].

Net N mineralization during an aerobic soil incubation was assessed with ~25 g of sieved, field-moist soil from each plot that was moistened to 60% water-filled pore space and placed in an incubator at 21 °C for 28 d. Mineral N concentration in 0.5 M K_2SO_4 extracts of the incubated soil (after 28 d) was determined colorimetrically, as described above. Net mineralization rate (mg NH_4·kg soil^{-1}·d^{-1}) and net nitrification rate (mg NO_3-N·kg soil^{-1}·d^{-1}) were the difference in NH_4-N or NO_3-N concentration of the collected field-moist soil (initial) and the incubated soil divided by incubation time. Soil mineral N supply was the sum of the net mineralization and net nitrification rates for a given soil, at a given sampling point.

Statistical analysis

Data residuals were tested for normality with the Kolmogorov–Smirnov test in the PROC UNIVARIATE procedure of SAS (version 9.1). For each site, the effects of fertilizer N and canola growth stage on soil NH_4-N, NO_3-N, soil MBN, and soil mineral N supply were evaluated with a repeated measures ANOVA using PROC MIXED with canola growth stage as the repeated measure. The effect of fertilizer N and canola growth stage on canola N uptake at each site was assessed with PROC GLIMMIX, to account for missing data at the Ste-Anne site, with canola growth stage as the repeated factor. Significant effects ($P < 0.05$) were analyzed using Scheffe's multiple comparisons test at the 95% confidence level.

Table 1. Analysis of variance of the effects of nitrogen fertilizer rate and plant growth stage on soil nitrogen pools in canola fields at three sites in eastern Canada in 2012.

	Source of variation		
Soil characteristic	Fertilizer N rate	Growth stage	Rate × Stage interaction
		Ste-Anne	
NO_3-N ($mg \cdot kg^{-1}$)	<0.001	<0.001	<0.001
NH_4-N ($mg \cdot kg^{-1}$)	<0.001	<0.001	<0.001
MBN ($mg \cdot kg^{-1}$)	NS	<0.001	NS
Mineral N supply ($mg \cdot kg^{-1} \cdot d^{-1}$)	NS	<0.001	NS
		Quebec	
NO_3-N ($mg \cdot kg^{-1}$)	NS	<0.001	<0.001
NH_4-N ($mg \cdot kg^{-1}$)	NS	<0.001	NS
MBN ($mg \cdot kg^{-1}$)	NS	<0.001	NS
Mineral N supply ($mg \cdot kg^{-1} \cdot d^{-1}$)	NS	<0.001	NS
		Ottawa	
NO_3-N ($mg \cdot kg^{-1}$)	<0.001	<0.001	NS
NH_4-N ($mg \cdot kg^{-1}$)	NS	<0.001	NS
MBN ($mg \cdot kg^{-1}$)	NS	<0.001	NS
Mineral N supply ($mg \cdot kg^{-1} \cdot d^{-1}$)	NS	<0.001	NS

Note: N, nitrogen; NO_3-N, nitrate; NH_4-N, ammonium; MBN, microbial biomass N; NS, not significant. Mineral N supply refers to the net nitrogen mineralization and nitrification rates.

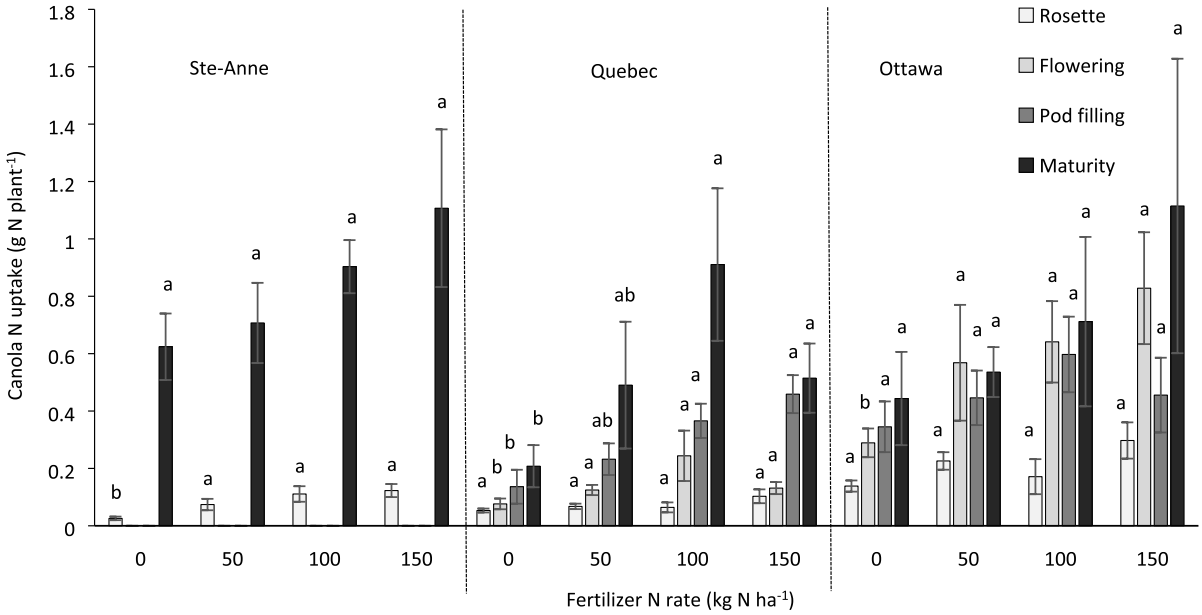
Results and Discussion

The mineral N concentration varied significantly with growth stage ($P < 0.001$), but did not respond consistently to fertilizer N rates across sites (Table 1). At Ste-Anne, soil NO_3-N and NH_4-N concentrations, as well as soil NO_3-N concentration in Ottawa, varied significantly with higher fertilizer N rates ($P < 0.001$, but did not affect the NH_4-N concentration in Ottawa or the mineral N concentration in Quebec (Table 1). The fertilizer N source was urea, which is hydrolyzed to ammonia and protonated as NH_4^+, so we expected NH_4-N to be biologically transformed via ammonia oxidation. This was the case at the Quebec and Ottawa sites, which generally had <10 mg NH_4-N·kg^{-1} in topsoil (0–20 cm depth) during the 2012 season (Gurung 2014). However, at the Ste-Anne site, the higher extractable NH_4-N concentration in fertilized plots at the rosette stage (from 5.0 to 43 mg NH_4-N·kg^{-1} in the 0–5 cm depth) compared with the unfertilized control (0.8 mg NH_4-N·kg^{-1} in the same depth; Gurung 2014) suggests that ammonia oxidation was constrained during early canola growth, possibly because of a limited carbon supply due to no crop residues from the previous season. By canola maturity, the NH_4-N concentration at the Ste-Anne site was <4 mg NH_4-N·kg^{-1} in topsoil (Gurung 2014). Ammonia oxidation and nitrification likely contributed to the elevated NO_3-N concentration in N-fertilized plots at Ste-Anne (from 34 to 79 mg NO_3-N·kg^{-1} with N fertilizer vs. 15 mg NO_3-N·kg^{-1} in unfertilized plots at 0–5 cm depth, rosette stage) and Ottawa (from 18 to 56 mg NO_3-N·kg^{-1} with N fertilizer vs. 10 mg NO_3-N·kg^{-1} in unfertilized plots at 0–5 cm depth, rosette stage; Gurung 2014). Another study of soil N dynamics in canola fields around the Ottawa region reported 6 to 10 times greater NO_3-N concentration than NH_4-N concentration in this humid temperate region (Ma and Herath 2016). The biological processes that transform fertilizer N to NO_3-N need to be monitored due to the vulnerability of NO_3-N to run-off, leaching, and denitrification (St. Luce et al. 2011).

The MBN concentration and soil mineral N supply varied significantly with growth stage ($P < 0.001$) but were not affected by the fertilizer N rate (Table 1). This suggests that the microbial biomass has a fixed capacity to immobilize fertilizer N and remains relatively constant, regardless of changing soil conditions and nutrient availability during the growing season, which is similar to other reports (Puri and Ashman 1998). Furthermore, varying the fertilizer N rate did not change the net N mineralization and nitrification rates, meaning that soil mineral N supply at these field sites were more dependent on organic N in the soil than fertilizer N application.

The lowest canola N uptake at Ste-Anne was measured at rosette stage in the 0 kg N·ha^{-1} treatment, but at 90% maturity, canola N uptake was similar across fertilizer rates (Fig. 1). Still, the soil NO_3-N concentration remained elevated in the 150 kg N·ha^{-1} treatment at maturity, with 6.9 mg NO_3-N·kg^{-1} in the 0–5 cm depth, relative to plots

Fig. 1. Canola N uptake (g N·plant^{-1}) at three sites in eastern Canada in 2012 (Ste-Anne, Quebec, and Ottawa sites). Canola received four different fertilizer rates (0, 50, 100, and 150 kg N·ha^{-1}) and canola N uptake was measured at four growth stages (rosette, flowering, pod filling, and maturity). Different lowercase letters indicate significant differences among fertilizer N rates within each growth stage at a given site. Canola N uptake differed between growth stages ($P < 0.001$ for all sites), but the N rate × growth stage interaction was not significant ($P > 0.05$ for all sites). Data from flowering and pod filling stages were missing from the Ste-Anne site. N, nitrogen.



that received 0, 50, or 100 kg N·ha^{-1} and contained ≤1.6 mg NO_3-N·kg^{-1} (Gurung 2014). This indicates that canola did not use all of the mineral N supplied in the 150 kg N·ha^{-1} treatment, an undesirable agro-environmental outcome. At the Ottawa site, soil NO_3-N was highest in plots receiving 150 kg N·ha^{-1} at maturity (15 mg NO_3-N·kg^{-1} in the 0–5 cm depth) and lowest in unfertilized plots (3.9 mg NO_3-N·kg^{-1} in the 0–5 cm depth; Gurung 2014), but canola N uptake was similar among fertilizer N rates at each growth stage (Fig. 1). At Quebec, canola required at least 50 kg N·ha^{-1} for optimal growth and there was no change in canola N uptake when 100 or 150 kg N·ha^{-1} was applied. Previous work by Ma and Herath (2016) on canola in eastern Canada found that the majority (>50%) of canola N uptake was from soil mineral N rather than fertilizer N, based on three canola growing seasons. Therefore, the recommended rate of 100–150 kg N·ha^{-1} for canola in Quebec and Ontario will meet the crop requirements, based on canola N uptake.

We acknowledge that canola N uptake does not always translate into greater yield or improved nitrogen use efficiency. In a companion paper, Ma et al. (2020) found that canola yield plateaued when 150 kg N·ha^{-1} was applied to the Quebec and Ste-Anne sites, whereas maximum yield was achieved with 75 kg N·ha^{-1} plus supplemental sulfur (S) at 20–40 kg S·ha^{-1} at the Ottawa site. Consequently, there is an opportunity to fine-tune the fertilizer N recommendation in eastern Canada on a site-specific basis, and it is important to also consider S requirements of canola.

Conclusion

The contrast in soil N dynamics and canola N uptake at three sites highlights the importance of site-specific management practices for growing canola in eastern Canada. Three sites within 400 km of each other responded uniquely to the same fertilizer N rate applied to the same canola hybrid. Diagnostic tools based on nutritional indices or proximal chlorophyll meters may have potential to resolve the spatio-temporal heterogeneity in canola N nutrition to make timely fertilizer decisions in eastern Canada.

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